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LATE PLEISTOCENE OSCILLATIONS OF SEA-LEVEL IN THE OTTAWA VALLEY

by

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Late Pleistocene Oscillations of Sea-level in the Ottawa Valley.

By W. A. JOHNSTON.

INTRODUCTION.

It has long been known that during late Pleistocene time an arm of the Atlantic extended westward far up the St. Lawrence and Ottawa valleys. Extensive deposits of marine clays, known as the Champlain or Leda clays, and old sea beaches, at considerable heights above sea-level, have long been known to occur in the St. Lawrence and Ottawa valleys and have furnished evidence that the land had been depressed relatively to sea-level and had subsequently emerged. It is known that stratified sands and clays holding fossil marine shells occur in the Ottawa valley at various altitudes up to at least 480 feet above the sea and that old sea beaches occur at higher altitudes; but there has been doubt regarding the upper limit of marine submergence because of contradictory opinions expressed by different investigators. It is known that the upper limit of the marine deposits rises gradually towards the north, but altitudes of the raised beaches in this region have been determined at very few localities so that comparatively little is known regarding the extent and character of the differential uplift which affected this portion of Canada during late Pleistocene time. (Pleistocene time is herein considered to have ended and Recent time to have begun after the disappearance of the ice-sheet and when sea and land had, approximately, attained their present relationship.)

The marine fauna of the Champlain deposits in the St. Lawrence and Ottawa valleys was studied by Sir J. W. Dawson, J. F. Whiteaves, H. M. Ami, and other geologists, and considerable information has been published regarding the character and distribution of the fauna, but the significance of the fauna with regard to the oscillations of sea-level has not been fully considered.

The following is a brief summary of the results of field work done largely during the field season of 1915. The area in the vicinity of the city of Ottawa was especially studied, but numerous localities in the Ottawa valley, from Montreal 100 miles east of Ottawa to Renfrew 60 miles west of Ottawa, were also examined.

Acknowledgments are due to J. Keele of this Department for co-operation in the field work during part of the field season, and to I. E. Stewart who acted as assistant.

THE GLACIAL DEPOSITS AND DIRECTIONS OF ICE MOVEMENTS.

The glacial deposits in the Ottawa valley consist of till or boulder clay and fluvioglacial sands and gravels. These deposits are generally concealed by a covering of marine sediments, but in places they appear at the surface. Where seen in sections they are generally found to have no great thickness. They are irregularly distributed and over large areas the bedrock outcrops with little or no drift covering. In places, also, the marine clays rest directly on the bedrock. In some sections the glacial deposits show the three-fold division, upper till, middle sands (fluvioglacial), and lower till. In places, the fluvioglacial sands appear at the surface with no till covering and outcrop as ridges or irregularly shaped hills. Their fluvioglacial origin is shown by the markedly cross-bedded character of the bedding, the coarseness of much of the material, and by the faulting and crumpling of the beds as if from settling following the melting of included ice masses. They probably have little significance as regards a lengthy retreat of the ice. The upper till sheet, in places, includes lenses or irregular masses of stratified sands and gravels resembling the underlying fluvioglacial deposits. These masses, in some cases at least, appear to be "boulders" incorporated in the till sheet by the ploughing up of the underlying deposits by the ice; for they are irregular in shape and the underlying sands are in places disturbed as if by the overriding of the ice.

There are at least two distinct sets of striæ in the district, as has been noted by other writers.[1] One set, which is the more pronounced, trends nearly south; the other, which is the later, trends nearly southeast. This shows, at least, a marked change in direction of movement of the ice-sheet during the closing stage of glaciation.

No well marked terminal moraines occur in the vicinity of Ottawa; but, between Ottawa and Montreal, a strongly marked kettle moraine or series of moraines, showing characteristic knob and basin topography, extends southwestward from a point on the Ottawa river a few miles below Hawkesbury, through Alexandria and beyond, towards the St. Lawrence river. This moraine or series of moraines appears to mark the culmination of a slight readvance of the ice during the latest stage of Pleistocene glaciation.

No marine sediments are known to be overlain by glacial till in the Ottawa valley and no deposits which might be regarded as interglacial are known to occur. It is possible that the region was invaded by ice-sheets during early stages of Pleistocene glaciation; but, if so, no definite records have been left, so far as is known. It is probable that the glacial deposits in the region all belong to the latest or Wisconsin stage of glaciation.

EXTENT OF THE CHAMPLAIN SEA.

It is impracticable to definitely trace the northern boundary of the Champlain sea at its maximum extent in the Ottawa valley because of the weakness of development of the highest shore-line and because of the character of the rocky upland area which is unfavourable for the development of shore-line features; but

[1]Wilson, W. J., "Notes on the Pleistocene geology of a few places in the Ottawa valley," The Ottawa Naturalist, vol. XI, No. 12, 1898, pp. 209-220.

Ells, R. W., "Report on the geology and natural resources of the area included in the map of the City of Ottawa and vicinity," Geol. Surv., Can., 1901, p. 18G.

altitudes of the highest beach, determined at a few localities, and the distribution of the marine sediments show that, in general, the northern boundary lay along the face of the Laurentian Plateau escarpment, which borders the lowlands on the south and trends in a nearly east and west direction, roughly parallel to the course of the Ottawa river, and at a distance, generally, of only a few miles north of the river. Several long, narrow embayments, however, extended far up the valleys of the rivers which flow from the north and join the Ottawa. The sea extended far up the Ottawa valley, possibly as far as the head of Lake Timiskaming. Marine fossils are known to occur in the clays as far west as Lake Coulonge, about 70 miles west of Ottawa. Above this point the Ottawa valley is narrow, so that during the time of marine submergence the upper part of the valley was a long, narrow estuary.

The southwestern margin of the sea has not been traced, but it is known from the altitudes of the raised beaches and from the distribution of the marine sediments that it was bounded, approximately, by the eastern border of the Pre-Cambrian upland area in south-central Ontario. The shore-line extended southward from the vicinity of Renfrew to near the eastern end of Lake Ontario. At the highest stage of marine submergence, the portion of the triangular area between the Ottawa and St. Lawrence rivers, lying east of a line drawn from Ottawa to Brockville, was entirely submerged except for a few isolated hills. It has long been known that the upper as well as the lower portion of the St. Lawrence valley was also submerged and that the level of the marine waters extended westward into the Ontario basin; for, although marine, fossil shells are known to occur in the clays only as far westward as Brockville on the St. Lawrence, yet, the clays are continuous westward and the marine fossils occur at such high altitudes as to make it certain that the marine waters entered the Ontario basin.[1] In the upper St. Lawrence valley, however, the submergence was not so great as in the Ottawa valley; for the Ottawa valley lies at a lower level and was depressed to a greater extent, as is shown by the higher altitudes of its marine deposits.

[1]Coleman, A. P., "Marine and freshwater beaches of Ontario," Bull. Geol. Soc. Am., vol. 12, 1901.

The Upper Limit of Marine Submergence.

The upper limit of marine submergence in the vicinity of Ottawa was determined in 1891 by Baron Gerard de Geer of Sweden. The altitude of the highest shore-line, as determined by barometer, was found by de Geer to be 705 feet above the sea.[1]

In 1903, R. Chalmers stated that he had remeasured the altitude of the highest shore-line at Kingsmere, near Ottawa, and found it to be 910 feet above the sea.

Considerable difficulty arises in attempting to determine the highest shore-line in the Ottawa valley owing, partly, to the fact that the highest beach is never strongly developed, as, apparently, the sea did not stand long at the highest level, and partly because at the higher altitudes the slopes are generally steep and rocky with little drift covering so that little material was available for construction of wave-built features. Two of the most favourable localities for observing the shore-line are at Kingsmere, 8 miles northwest of Ottawa, and at Rigaud mountain, 70 miles east of Ottawa and 30 miles west of Montreal.

The Kingsmere locality is one of the most favourable localities in the Ottawa valley for the determination of the upper marine limit because of the occurrence of a sheet of boulder clay on the southern slope of the "mountain" and because of the good exposure to wave action. In the stream valley leading up to Kingsmere from the east, a deposit of stratified sands and gravels occurs, overlying stratified clay. The upper limit of the stratified sands and gravels is sharply defined and forms a terrace. The altitude of the inner edge of the terrace, as determined by levelling from the first road corner above this locality, the altitude of which is given on the Ottawa map sheet, issued by the Department of Militia and Defence, as 796 feet, was found to be 688 to 690 feet above the sea. The boulder clay slope rises to an altitude of over 200 feet higher, but no evidence of wave action could be found above an altitude of 690 feet. This locality is probably the same as that at which de Geer determined the altitude of the highest shore-line to be

[1] De Geer, Gerard, "On Pleistocene changes of level in eastern North America," Proc. Nat. Hist. Soc., Boston, vol. XXV, 1892, pp. 454-477. (Map.)

705 feet. The difference in altitude may be due to the fact that the altitude as found by de Geer was a barometric determination, which would readily account for the slight difference. It is not known on what grounds Chalmers chose the higher altitude.

The stratified clays underlying the sands and gravels in the valley leading up to Kingsmere contain fossil marine shells at various altitudes up to at least 510 feet. The clays are exposed at intervals in the bed of the creek at higher altitudes, their upper limit being about 605 feet, and there can be little doubt that they are all marine. This occurrence of stratified clays strongly supports the physiographic evidence as to the upper limit of marine submergence at this place, so that it is probable that, during the maximum stage of marine submergence, the sea stood at about 688 to 690 feet.

At Rigaud mountain occurs the remarkable series of cobblestone beaches which have been described by several geologists and an effort was made to determine the highest shore-line at that locality. The most favourable place was found to be along St. George road, near the central portion of the mountain, where boulder clay slopes occur at altitudes of from 600 to over 700 feet. Along St. George road and about one-quarter mile west of the crossing of the road leading south from Rigaud village, a small but well formed gravel beach ridge or bar occurs, which appears to mark the upper limit of marine submergence at this locality. The crest of the gravel ridge has an altitude of 671 feet above sea-level, as determined by levelling from a bench-mark established at Rigaud station by precise levelling done by the Department of Public Works. Below an altitude of 600 feet and down to about 200 feet, at Rigaud mountain, the beaches are remarkably well developed and closely spaced. This is especially the case at altitudes from 300 to 500 feet. An exceptionally strong beach also occurs at 207 feet. The remarkable strength of development of the beaches at this locality was due, doubtlessly, to the fact that, during the submergence, the mountain formed an island exposed on all sides to storm waves with an abundance of material on the slopes for the waves to handle. The closely spaced character of the beaches shows that an almost continuous emergence of the land took place, but probably with a more rapid emergence at the highest levels and a slowing down at the lower levels.

The altitudes of the highest raised beaches at Rigaud and Kingsmere show that, in this portion of the Ottawa valley, the direction of maximum uplift was probably slightly west of north, for the Rigaud locality at which the highest beach was measured is about 3 miles south of the latitude of the Kingsmere locality and the highest beach at the latter place is 17 to 19 feet higher than at the former; but the information is not very definite because the rate of tilt is not known.

Altitudes of Raised Beaches at Lower Levels.

Raised beaches occur throughout the Ottawa valley at numerous localities and at various altitudes, but it is impossible in most cases to trace individual beaches for any great distance, so that the altitudes of the lower beaches furnish little information regarding the direction of maximum uplift and rate of tilt. One beach, however, which can be traced for a considerable distance, was found to occur in the valley of the Ottawa river above the city of Ottawa. This beach probably marks the outline of a lake which was formed after the partial or complete withdrawal of the marine waters, for no marine fossils are known to occur in its deposits and in the vicinity of Ottawa strongly marked river terraces and river gravels occur at altitudes nearly corresponding to the altitudes of the beach in the upper part of the basin. Altitudes of this beach were determined at several localities as follows:

	FEET.
Two miles southeast of Breckenridge, near the Canadian Pacific railway, crest of strong gravel bar	264
Three miles northwest of Aylmer and one-quarter mile north of the railway, crest of gravel beach ridge	256
At Aylmer, 100 yards northwest of the Canadian Pacific Railway station, crest of strong gravel barrier beach	252
One-half mile north of Fraser's mills, crest of sand and gravel beach	247
One-half mile west of Taylor's wharf, crest of strong sand and gravel spit	250
One and one-half miles northwest of Dunrobin Post-Office, near the cross-roads, crest of strong gravel beach	260
One-quarter mile northeast of South March Post-Office, base of terrace and bluff cut in marine clay	242

The altitudes are all in feet above sea-level and are, with the exception of the last two, based on precise levels; that is, the altitudes were determined by levelling to or from the water-level of Lake Deschenes or the expansion of the Ottawa river above the lake proper, the altitude of which at the time was determined from bench-marks established by precise levelling done by the Department of Public Works. The last two altitudes were

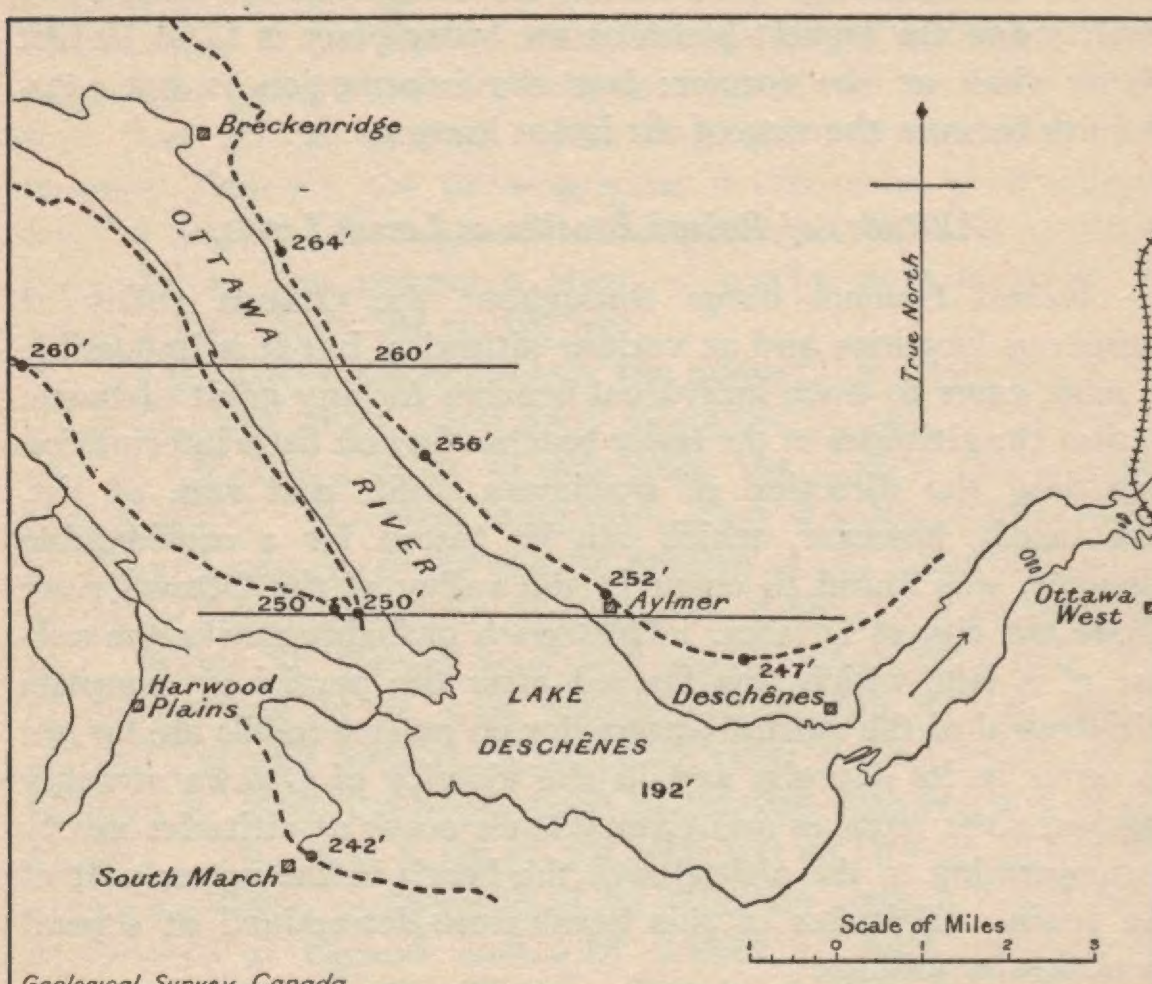

Figure 1. Raised beaches in the Ottawa valley, showing altitudes in feet above sea-level, and isobases.

determined by levelling from road corners, the altitudes of which were determined by levelling done by the Department of Militia and Defence.

The shore-line of a portion of this lake is shown on the accompanying outline map. Altitudes of the shore-line in feet above sea-level and isobases at an interval of 10 feet are also shown.

In the southern part of the basin altitudes of the shore-line are not definitely determinable because, apparently differential uplift caused a transgression of and a cutting away of the original shore-line in this part of the basin. The altitudes of this beach are not sufficiently numerous to accurately determine the direction of maximum uplift and rate of tilt, but they show, approximately, that the differential uplift which affected this area during the life of and after the disappearance of the lake was greatest in a nearly due north direction and that the rate of tilt is about 3 feet per mile over part of the basin. The high rate of tilt as shown by the deformation of this beach is remarkable when it is considered that the present altitudes of the beach record only the differential uplift which took place during the latest stages of the marine submergence. It also shows that the region north of the Ottawa river was probably affected by a greater amount of uplift than has affected the Ottawa region.

It is known that the direction of maximum uplift over a great part of the Great Lakes region is in a direction about north 20 degrees east. The change of direction to nearly north in the Ottawa valley nearly coincides with the direction of general glaciation. This supports the view that the uplift of the land was due to isostatic readjustment following the removal of the burden of the ice-sheets, which theory has at least a high degree of probability to support it.

Character of the Champlain Clays.

The Champlain or Leda clays, as they were named by J. W. Dawson, have long been known to be widespread in the Ottawa valley and to have a maximum thickness, in places, of nearly 200 feet. They are exposed in numerous sections in the vicinity of Ottawa, at various altitudes from 130 feet, in the lowest part of the Ottawa valley, up to 600 feet above sea-level, the highest locality at which they are known to occur being in the stream valley leading up to Kingsmere from the east.

In physical character the clays are markedly different in their upper and lower portions. The lower portion is a sandy and silty clay often well laminated, especially towards the base.

It occurs practically at all altitudes from 130 feet up to 600 feet. In the lower portions of the Ottawa valley it is generally finer grained and contains less silt and sand. In its upper portion the lower clay in places passes upward into sand. This occurs most markedly at altitudes from 200 up to 350 feet. In places, as along the Rideau river near Rideau junction, the sand overlying the lower silty clay is as much as 20 feet thick and is overlain by the upper clay. The sand is generally evenly bedded but often strongly ripple-marked. In the lower portion of the Ottawa valley near Ottawa the sand is generally thin or absent and the lower silty clay is overlain directly by the upper clay. The lower clay shows every evidence of the presence of floating ice. Glaciated stones and boulders occur abundantly in the lower portion of the clays and the beds in many places are crumpled and contorted as if by the grounding of icebergs. This is well seen in sections exposed along the shore of Lake Deschenes at the foot of Graham bay, at Black rapids on the Rideau river, and in the bed of the brook leading up to Kingsmere from the east. The contorted beds are in places overlain and underlain by undisturbed beds showing practically contemporaneous deformation. The lower silty and sandy clays form the greater portion of the marine sediments and there can be little doubt that they were derived from the waters of the melting ice-sheet which could not have been far distant when the clays were deposited.

The upper clay overlies the lower sandy and silty clay at practically all altitudes from the lowest part of the Ottawa valley up to at least 425 feet. It is generally only 6 to 10 feet thick, but in places has a maximum thickness of 20 feet or possibly more. The upper clay differs markedly in physical character from the lower clay. It is an exceedingly fine-grained plastic clay generally interlaminated with sandy bands in its lower portion near the contact with the underlying sandy or silty beds, but becoming nearly free from sand in its upper portion. Boulders occur occasionally in and on the surface of the clays as if dropped from floating ice or ice-floes in the manner described by Hind,[1] but the upper clays are not known to be crumpled or disturbed except where landslides have occurred. The

[1]Canadian Monthly, Sept., 1875.

physical character of the upper clay shows that it was largely derived from the erosion of land surfaces by stream and wave action. It must have been deposited in a considerable depth of water because of its fineness and the even, undisturbed character of its bedding.

The physical character of the Champlain clays in the Ottawa district shows that different climatic and physical conditions existed during the times of deposition of the lower and upper clay. Up to the time of maximum submergence of the land the ice-sheet was probably not far distant, but during the greater part of the time when emergence of the land was taking place the ice had retreated far to the north. The physical character of the marine deposits also suggests that the sea rose on the land as the ice-sheets retreated.

The Significance of the Molluscan Fauna of the Champlain Clay.

Fossil marine shells of species of mollusca occur abundantly in the Champlain clays of the Ottawa district, but they are confined almost exclusively to the lower clays. The commonest and most characteristic fossil shell found in the lower clay is *Portlandia* (*Yoldia*) *artica* Gray (=*Leda glacialis*), from the abundant occurrence of which in the clay the name "Leda clay" was given by J. W. Dawson. The molluscan fauna of the lower clays in the Ottawa district also includes *Nucula tenuis* Mont., *Macoma calcarea* Chemn., *Saxicava rugosa* Lin., *Natica affinis* Gmel., *Neptunea despecta* Lin., *Cylichna alba* Brown, and *Astarte compressa* Mont. (?). Fossil shells of these species have all been found by the writer to occur in the lower clays at various localities in the vicinity of Ottawa. They have with one or two exceptions been previously reported to occur in the clays of the Ottawa district.[1] These species of mollusca are all, in European waters, high arctic.[2] They are nearly all, however, known to be living in the colder parts of the Gulf of St. Lawrence. A notable exception is *Portlandia arctica* Gray, which is not known to occur

[1] Ami, H. M., Geol. Surv., Can., Ann. Rept., vol. XII, 1899, pt. C, Appendix.

[2] Brögger, W. C., "Om de Senglaciale og Post-glaciale Niraforondringer i Kristianiafeltet"; Norges Geologiska Untersgelse No. 31, 1901, p. 681.

south of the Strait of Belle Isle.[1] *Portlandia artica* "now only lives in sea water at a temperature below 0 degrees Centigrade and thrives in the muddy waters discharged at the mouth of glacier streams."[2] The silty lower clays holding *Portlandia artica* and other fossil shells of arctic species occur in the vicinity of Ottawa at altitudes from 130 feet in the lowest portion of the Ottawa valley up to at least 510 feet above sea-level, the highest locality, so far as known, being at the above-mentioned locality near Kingsmere. *Portlandia artica* also occurs in the sandy beds in the upper portion of the lower clay, as well as many of the other species; but the forms are generally small as compared with those of the lower portion, apparently showing an amelioration of temperature conditions. The fauna occurs in the lower clays most abundantly at altitudes from 175 feet up to 275 feet above sea-level.

The upper clays are generally nearly barren of fossil shells. This is especially the case in their upper portion. In the sandy layers interbedded with clay layers near the base of the upper clays, *Macoma Balthica* Lin. sometimes occurs in considerable numbers. *Saxicava rugosa* also occurs and, rarely, small forms of *Portlandia*. In general, though, the abundant and characteristic fauna of Arctic species found in the lower clays is absent in the upper clays.

As the typical and common species of the lower clays have been found to live abundantly in high arctic seas only at depths of from about 10 to 30 metres,[3] and as these clays in the vicinity of Ottawa occur at altitudes of from 130 feet up to at least 510 feet and occur abundantly at altitudes from 175 feet up to 275 feet above the sea, hence it is evident that the sea must have stood at a considerably lower level with respect to the land when the lower clays holding shells of arctic species were deposited in the lowest part of the Ottawa valley than when those at high altitudes were deposited. The clays at low altitudes could not have been deposited during the time of emergence of the land for they are

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[1] Whiteaves, J. F., "Catalogue of the marine invertebrata of eastern Canada." Geol. Surv., Can., 1901, p. 127.

[2] Wright, W. B., "The Quaternary Ice Age," p. 327.

[3] Brögger, W. C., *Ibid*, p. 681.

overlain by the upper clay, and the occurrence of abundant remains of *Macoma Balthica* in the littoral deposits in the district at altitudes of 470 feet and lower, and of *Mytilus edulis* Lin. at an altitude of at least 325 feet above the sea, shows that the climate was not high-arctic during the time of emergence of the land as *Mytilus edulis* on high-arctic shores is not a littoral shell and *Macoma Balthica* is more characteristically boreal than arctic.[1] The occurrence of the clays at high altitudes far up the Ottawa and Gatineau valleys also shows that the ice-sheet had retreated a considerable distance before emergence of the land had taken place to any great extent. Both the physical character of the clays, and the character of the fauna, therefore, seem to show that the sea must have risen on the land as the ice-sheet withdrew; that at first it stood at about 300 feet or possibly lower and later rose considerably higher.

This is exactly what has been shown by Brögger to have taken place in southern Norway. Brögger has held that the oscillation of sea-level was due to a depression of the land. Wright,[2] however, has pointed out that it is more probable that the sea rose on the land owing to the return to the ocean of the water which had been bound up in the ice-sheets, for the depression of the sea-level was "an absolutely necessary result of glaciation," as has been shown by the investigations of Penck, Woodworth, and Daly.

The rise of the sea on the land which, apparently, took place in the Ottawa valley was preceded by uplift which affected the Great Lakes region; for the Ottawa valley must have been, in part at least, occupied by the ice-sheet during the existence of Lakes Iroquois and Algonquin and at least a small amount of uplift affected the region at the foot of Lake Ontario during the life of Lake Iroquois.[3] Uplift also affected the northern portion of the Great Lakes region and probably included the upper portion of the Ottawa valley near Mattawa during the existence of Lake Algonquin and while the ice-sheet still occupied the upper

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[1] Brögger, W. C., *Ibid*, p. 693.

[2] Wright, W. B., "The Quaternary Ice Age."

[3] Coleman, A. P., "The Iroquois Beach in Ontario," Bull. Geol. Soc. Am., vol. XV, 1903, pp. 347-368.

portion of the Ottawa valley.[1] No evidence is known which would suggest that depression of the land subsequently affected the northern portion of the Great Lakes region or the upper portion of the St. Lawrence valley near the foot of Lake Ontario. It seems improbable that depression of the land took place in the Ottawa valley during the time of the retreat of the ice-sheet from this region, for the results of investigations by numerous geologists, of the raised beaches of the Great Lakes region, has shown that differential uplift took place almost continuously as the ice withdrew, but probably proceeded from south to north, so that the region well outside the borders of the retreating ice-sheet was affected by uplift before the more northerly regions were affected. The evidence so far as known suggests that the rise of sea-level which, apparently, took place in the Ottawa valley was due to a return to the sea of the waters which had been bound up in the ice-sheet and was not due to depression of the land.

[1] Taylor, F. B., Monograph LIII, U.S. Geol. Surv.

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In the case of Bulletins 1 and 2, which contain articles on various subjects, each article has been assigned a separate series number.

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